Refined Compressive Strain Capacity Models

Ming Liu[1], Fan Zhang[1], Kunal Kotian[1], and Steve Nanney[2]

Center for Reliable Energy Systems[1]
Dublin, OH, USA

US DOT PHMSA[2]
Houston, TX, USA

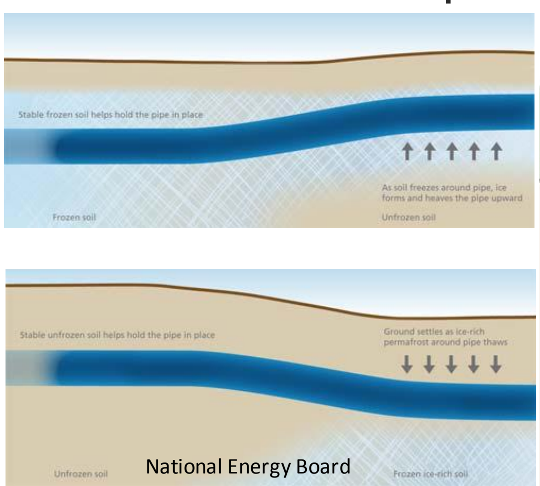
2014 10th International Pipeline Conference (IPC 2014)
Calgary, Alberta, Canada 10/01/2014

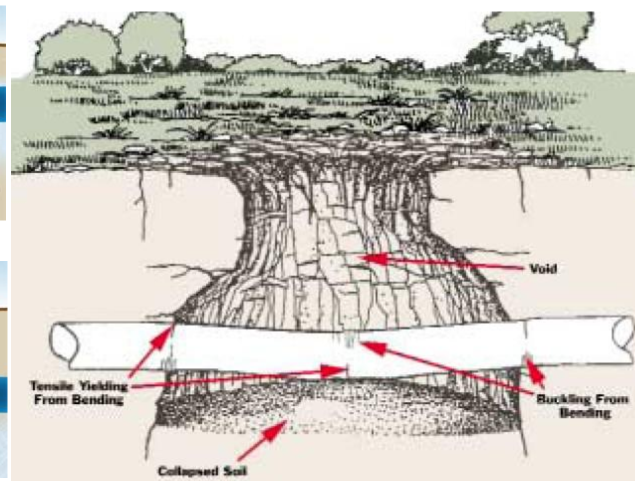
Overview

- Background
- Model development processes
- Model Key parameters
- Models
- Model evaluation
- Summary

Background

- Why compressive strain models are needed?
  - Ground movement and temperature change can induce compressive strain in the pipeline.
  - Excessive compressive strain forms wrinkles in the pipe which reduces its load carrying capacity.
  - Compressive strain capacity models are used to calculate the critical compressive strain.





Background

- Existing compressive strain models
  - Many existing models:
    - CSA Z662, DNV OS F101, API RP 1111, University of Alberta, JFE, and C-FER, etc.
  - Many differences:
    - Basis: experiments vs. numerical analyses or combined
    - Loading conditions: bending dominant, axial force typically not known
    - Recognized parameters: D/t, pressure, strength, strain hardening capacity, geometry imperfections, cross section ovality, girth weld high-low misalignment
    - Calculated strain capacity

Model Development Process

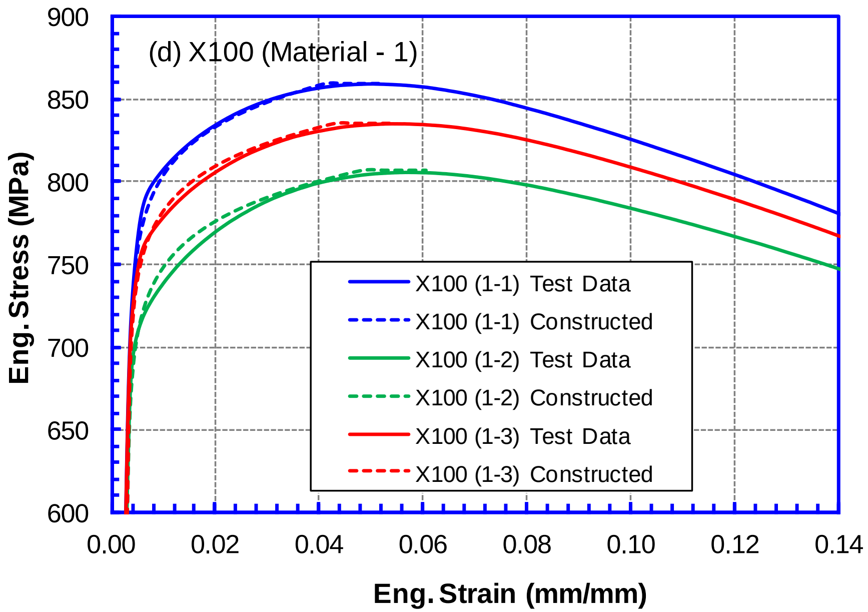
- What model development processes are?
  - How to represent/simulate the actual material and field conditions in finite element analyses,
  - They are the foundation of the compressive strain models.
- Why model development processes are important?
  - Actual material and field conditions are often complicated and have a lot of variations,
  - The differences in how the actual conditions were simulated in the existing models partially contributed to the difference of the models,
  - Need consistent and realistic modeling processes to be able to
    - Consider the variations,
    - Represent those complicated conditions, and
    - Keep the modeling efforts manageable.

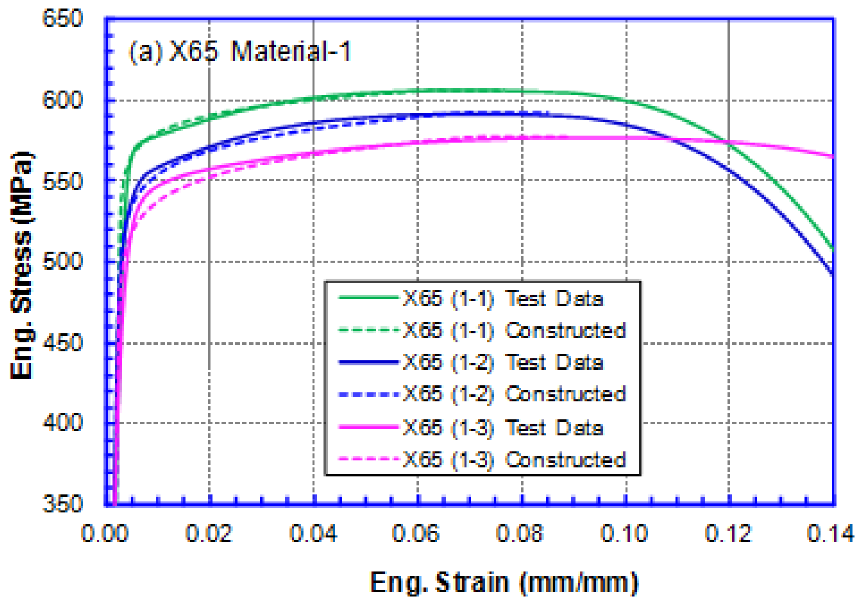
Model Development Processes

- Key elements of the model development processes
  - Representation of the material properties
  - Representation of loads and constraints in the field
  - Representation of loading sequences
  - Measure of compressive strain capacity
  - Length of specimen

Representation of Material Properties

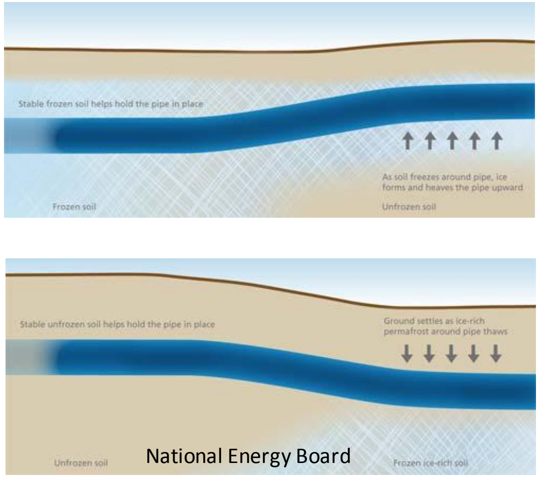
- Full stress-strain curves vs. key material parameters
  - Full stress-strain curves (SSC) are represented by material parameters, e.g., YS, Y/T, uEL
  - The same set of material parameters may correspond to different SSC
  - The procedures for the PRCI-CRES tensile strain models were used.

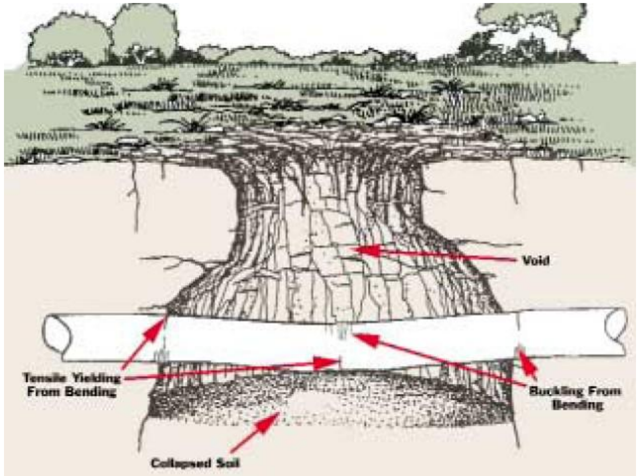


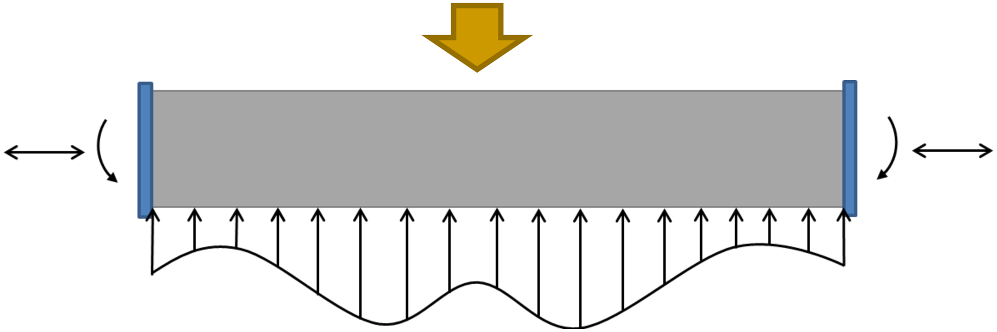


Representation of Load and Constraint

- The load applied to a pipeline can be complicated





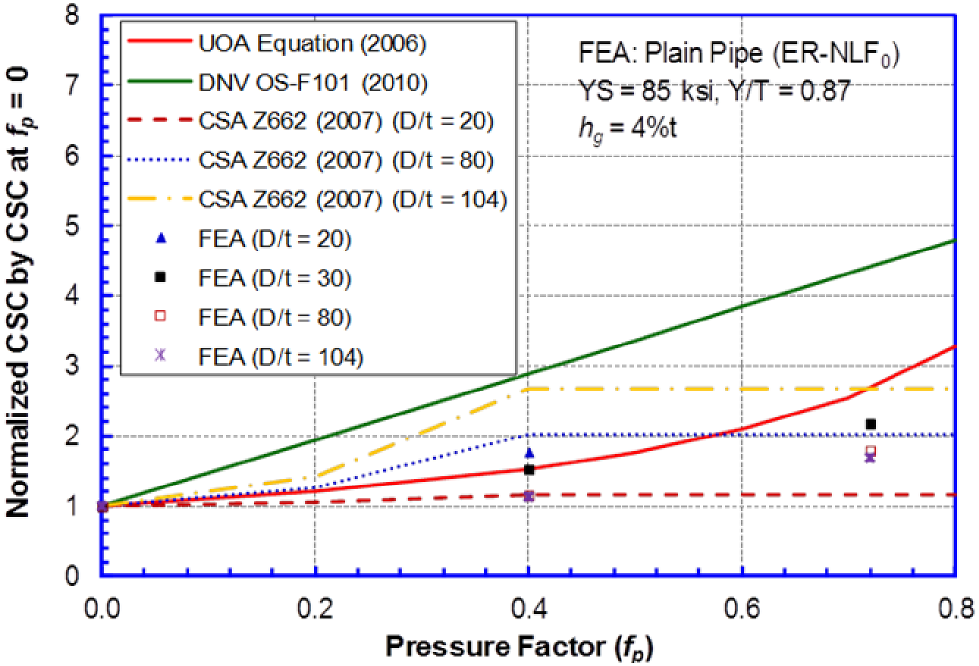


Influencing Parameters

- Pipe's geometries: D/t ratio;
- Loading conditions:
  - Internal pressure and
  - Longitudinal net-section force (tension);
- Pipe properties:
  - Yield strength,
  - Strain hardening exponent (pipe's Y/T ratio),
  - Lüder's strain,
  - Material anisotropy (different axial/hoop SSC);
- Geometry imperfections:
  - Cross section ovality
  - Longitudinal surface undulation;
- Girth welds:
  - Strength mismatch, cap size, and residual stress
  - High-low misalignment.

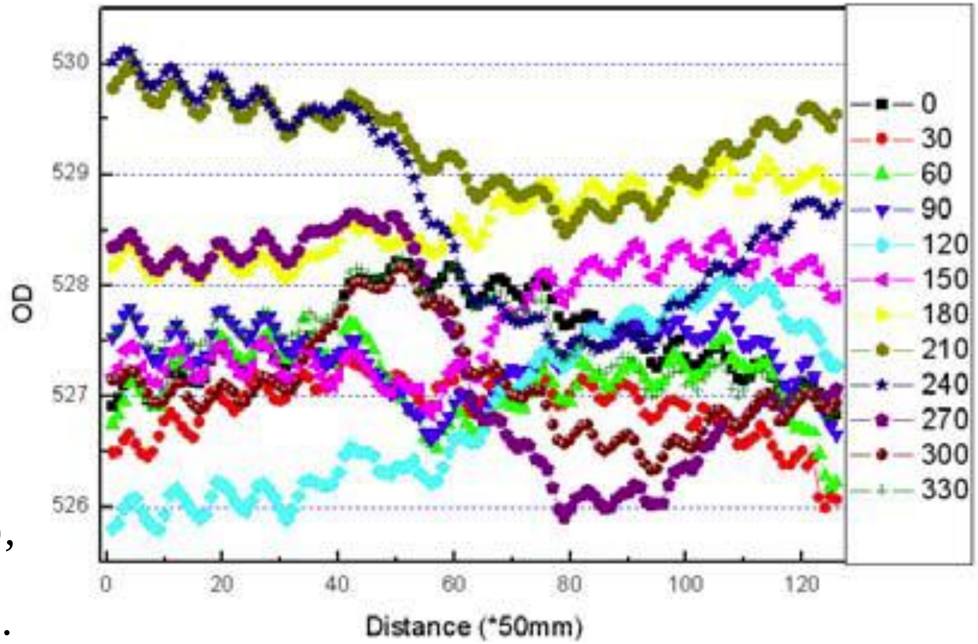
Effect of D/t and Pressure

- The increase of CSC due to internal pressure is higher for small D/t pipes
- Most models didn't capture the pressure effect very well



Effect of Geometry Imperfections

- What is the geometry imperfections (surface undulation)?
  - Results of cold expansion
- Both imperfection height and length are important to the CSC
  - Critical length: 20%-60% OD
- Most models didn't consider this parameter
- Recommended height based on actual measurement



Median $h_g = \max(0.13\%D, 8\%t)$,

Lower Bound $h_g = \max(0.05\%D, 1\%t)$,

Upper Bound $h_g = \max(0.2\%D, 15\%t)$.

Refined Models

- Parameters adopted in the refined models
  - Pipe D/t ratio;
  - Internal pressure;
  - Geometry imperfection;
  - Pipe Y/T ratio;
  - Pipe uniform strain;
  - Pipe Lüder's strain; and
  - Net-section stress (only tension currently).

$$\varepsilon_c^{\text{crit}}(\%) = \min(\varepsilon_u, F_{LD} * \varepsilon_r),$$

$$F_{LD} = \begin{cases} \cancel{\varepsilon_r} \left\{1 - 0.50 * (1 - 0.75\varepsilon_r{}^{-0.23}) \left[1 + \tanh\left(8.0\frac{\varepsilon_e}{\varepsilon_r} - 8.2\right)\right]\right\} & \text{SSC with Lüder's strain} \\ 1 & \text{Round SSC} \end{cases},$$

$$\varepsilon_r(\%) = F_{DP} * F_{YT} * F_{GI} * F_{NF},$$

$$F_{DP} = \begin{cases} 980 * \left[0.5\left(\frac{D}{t}\right)^{-1.6} + 1.9 * 10^{-4}\right], & \text{if } f_p < f_{pc} \\ 980 * (1.06 f_p + 0.5)\left(\frac{D}{t}\right)^{-1.6}, & \text{if } f_p \geq f_{pc} \end{cases},$$

$$f_{pc} = 1.8 * 10^{-4} * \left(\frac{D}{t}\right)^{1.6},$$

$$f_p = \frac{p_i D}{2t\sigma_y},$$

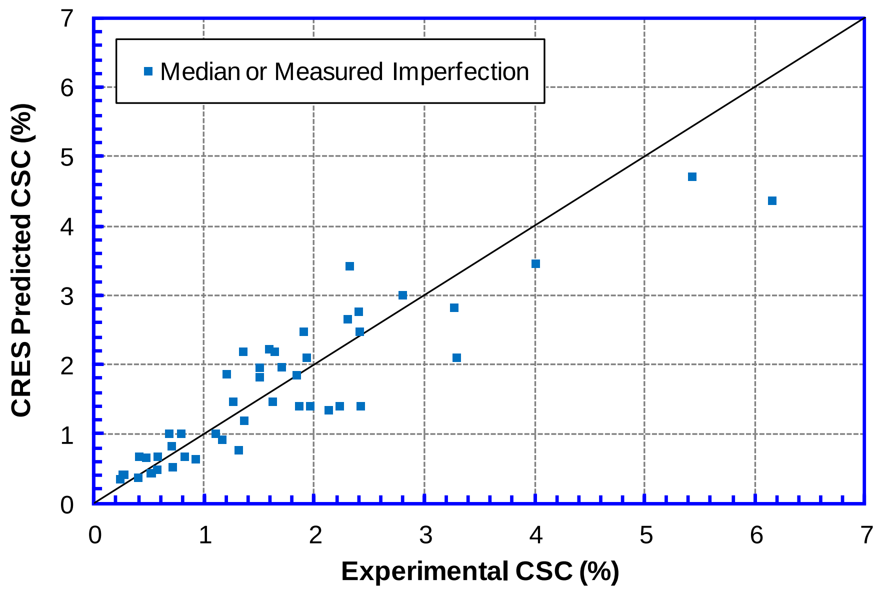
$$F_{YT} = 2.7 - 2.0\frac{\sigma_y}{\sigma_u},$$

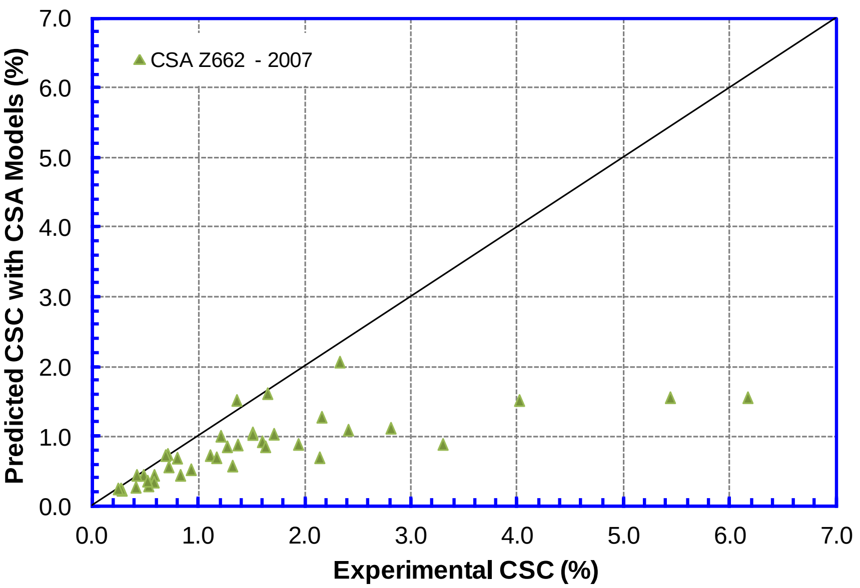
$$F_{GI} = 1.84 - 1.6\left(\frac{h_g}{t}\right)^{0.2},$$

$$F_{NF} = \begin{cases} 1.2 f_n{}^2 + 1, & \text{if } f_n \geq 0 \\ 1, & \text{if } f_n < 0 \end{cases},$$

Model Evaluation

- IPC2014-33680
  - Z. Zhang, Z. Yu, M. Liu, K. Kotian, and F. Zhang, "Application of compressive strain capacity models to multiple grades of pipelines".
  - Extended testing database: 52 tests
    - D/t: 22 – 104, X52 – X100, Y/T: 0.77 – 0.91, pressure factor: 0 – 0.8





Summary

- Refined compressive strain capacity models
  - Modeling processes
  - Influencing parameters
  - Evaluation of the models with experimental data
- Details of the technical work can be found in
  - DOT final report: Liu, M., Wang, Y.-Y., Zhang, F., and Kotian, K., 2013, “Realistic Strain Capacity Models for Pipeline Construction and Maintenance,” US DOT PHMSA #DTPH56-10-T-000016.
  - An early publication: Liu, M., Wang, Y.-Y., Zhang, F., Wu, X., and Nanney, S., 2013, “Refined Compressive Strain Capacity Models,” 6th International Pipeline Technology Conference, Ostend, Belgium.

Thank you!